TECHNICAL NOTE

D-1250

SUBSONIC WIND-TUNNEL INVESTIGATION OF ERRORS INDICATED BY TOTAL-PRESSURE TUBES IN THE FLOW FIELD OF A BODY SIMULATING THE NOSE OF THE X-15 RESEARCH AIRPLANE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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SUMMARY

A wind-tunnel investigation was conducted to determine the source of errors exhibited by a secondary total-pressure tube located on the upper surface of the fuselage of the X-15 research airplane with the nose boom. The effects of model-nose configuration, of the meridian plane of the total-pressure measurements, of changes in Mach number, and of the addition of a transition strip were investigated. The results indicated that a model configuration employing a nose boom suffered large losses of total pressure on the upper surface of the model. These total-pressure errors were presumed to result from the vorticity shed by the boom since no serious errors were noted for ball-nose or pointed-nose model configurations. The results also indicated that the lower surface would be a suitable circumferential location for the secondary total-pressure tube. The effects of increasing the Mach number from 0.60 to 0.80 and the effects of adding a transition strip to the configuration with a nose boom were negligible. The wind-tunnel measurements were in reasonable agreement with flight measurements of secondary-tube total pressures for configurations without and with nose booms.

INTRODUCTION

The X-15 research airplane has fuselage-nose configurations designed for both supersonic and hypersonic flight regimes. For the initial supersonic flights, the airplane utilized a pointed-nose configuration with airspeed and attitude instrumentation installed on a fuselage nose boom. For hypersonic flight, the airplane utilized a ball nose for sensing total pressure and for determining aircraft attitude by a null-pressure technique. A secondary total-pressure tube, mounted about 3 inches above the upper surface of the fuselage at a location approximately 1 foot ahead of the canopy windshield, was employed for flight-safety considerations.

For the configuration with the nose boom, flight experience indicated that, for subsonic Mach numbers as high as 0.80, the total pressures sensed by the secondary tube at positive angles of attack were generally less than those sensed by a total-pressure tube located on the nose boom. In an attempt to determine the source of errors incurred by the secondary total-pressure tube, wind-tunnel tests were conducted to measure total pressures in the flow field of a body simulating the nose section of the X-15 research airplane. Tests were designed to provide information concerning possible effects (on secondary-tube total pressures) of changes in nose configuration, changes in circumferential location of pressure-measuring instruments, a change in Mach number, and possible effects of adding a transition strip on the configuration employing the nose boom. The purpose of this paper is to present the results of the wind-tunnel investigation.

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SYMBOLS

d	local diameter at survey location (See fig. 1.)
y	distance between rake tubes and model surface
p_t	free-stream total pressure
$p_{t,l}$	local total pressure measured by tube
Δp_t	total-pressure error, $p_{t,l} - p_t$
p	free-stream static pressure
p_l	local static pressure
Δp	difference between local and free-stream static pressures, $p_l - p$
q_c	free-stream impact pressure, $p_t - p$
M	free-stream Mach number
α	angle of attack of body reference line, deg
ϕ	meridian angle (circumferential location) of total-pressure rake, deg (See fig. 1.)

MODELS AND APPARATUS

The three model configurations investigated are shown in figure 1. The pointed-nose model is an ogival body of revolution having approximately the same shape as the basic fuselage of the X-15 research airplane without the nose boom and protuberances. (Ordinates for this configuration are presented in table I.) The pointed-nose model with a nose boom represents the supersonic configuration, and the ball-nose model represents the hypersonic configuration of the airplane without fuselage-surface protuberances.

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A rake of unshielded total-pressure tubes was used to obtain surveys of local total pressures at a model location approximately corresponding to the location of the full-scale secondary total-pressure tube on the airplane. A single static-pressure tube adjacent to the total-pressure rake was used for sensing local static pressures at the survey location. Details of the test setup and the pressure-sensing devices are presented in figure 2. The pressures were measured on a multiple-tube manometer containing tetrabromoethane.

TESTS, CORRECTIONS, AND ACCURACY

The tests were made in the Langley high-speed 7- by 10-foot tunnel at free-stream Mach numbers of 0.6 and 0.8 with corresponding Reynolds numbers per foot of 3.53×10^6 and 4.26×10^6, respectively. The angle-of-attack range generally extended from -20° to 20°. The effects of the nose configuration, the meridian angle of the pressure rake, and Mach number were investigated. In an effort to assure turbulent flow, one test was made with a transition strip of No. 60 carborundum grains located on the model configuration with the nose boom as shown in figure 1.

No corrections have been made to the data to account for the differences between the total-pressure rake used in the wind-tunnel tests and the single total-pressure tube employed on the airplane; neither have corrections been made to account for interference effects between adjacent tubes on the rake. On the basis of reported characteristics of individual unshielded total-pressure tubes (ref. 1), it is believed that the tubes used in the present tests should be insensitive to local-flow incidence angles up to approximately 10°. Static-pressure measurements include no corrections for possible errors associated with cross-flow and with interference effects of the total-pressure rake.

Consideration of the methods employed for model support, tunnel setting, and pressure measurement indicated that possible random errors in the test data should be no larger than the following maximum-error estimates:

M	$\Delta p_t/q_c$	$\Delta p/q_c$	$\Delta p_t/p_t$
0.60	±0.010	±0.010	±0.002
.80	.006	.006	.002

In the analysis of the data, it should be noted that test conditions of positive angles of attack and a pressure-rake location of $\phi = 0^{\circ}$ corresponded to the conditions for the actual flight configuration, where the secondary total-pressure tube was located on the upper surface of the fuselage. Also, test conditions of negative angles of attack and a rake location of $\phi = 0^{\circ}$ can be considered as corresponding to a flight arrangement with the secondary total-pressure tube located on the lower surface of the fuselage.

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RESULTS AND DISCUSSION

The total-pressure results are presented as errors relative to free-stream total pressure and are nondimensionalized with respect to free-stream impact and total pressures. In general, these data are presented as functions of distance from the body surface (nondimensionalized with respect to the local body diameter) for various angles of attack and for Mach numbers of 0.60 and 0.80. The local static-pressure measurements obtained at a distance from the model surface of $y/d = 0.10$ are presented in coefficient form as a function of angle of attack.

The effects of changing nose configuration of the model are presented in figure 3. The effects of changing the meridian angle (circumferential location) of the total-pressure rake for the configurations with the nose boom and with the ball nose are presented in figures 4 and 5, respectively. The effect of a transition strip on the configuration with the nose boom is presented in figure 6. A comparison of total-pressure errors measured at the secondary-tube location in flight at the NASA Flight Research Center and in the wind tunnel is presented in figure 7.

In general, the variation of test Mach number from 0.60 to 0.80 had negligible effect on the total-pressure error although some influence of compressibility was evident in static-pressure coefficients. (See figs. 3 to 6.) The effects of changing the nose configuration on total pressures sensed by rake tubes at $\phi = 0^{\circ}$ were negligible at negative angles of attack for tube distances (from model surface) greater than $y/d = 0.02$ (fig. 3). At positive angles of attack, the total-pressure errors were large for the configuration with a nose boom, whereas the errors were small for the pointed-nose and ball-nose configurations without nose booms at y/d values greater than 0.04. The large losses of total pressure at positive angles of attack for the configuration with the nose boom were presumed to be associated with vorticity shed from the boom. The asymmetric nature of this type of vortex flow and its effects on the directional characteristics of bodies is discussed in reference 2.

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For the configuration with the nose boom, the effect of changing the meridian angle of the total-pressure rake from $\phi = 0^{\circ}$ to $\phi = 45^{\circ}$ was generally to increase the total-pressure errors at negative angles of attack and to reduce the errors at positive angles of attack up to 15° (fig. 4). Location of the rake at a meridian angle of 90° provided total-pressure errors which were larger, at positive angles of attack, than those with the rake at a meridian angle of 45°. The test results for the configuration with a nose boom (figs. 3 and 4) indicated that the lower surface of the fuselage would be a desirable circumferential location for a secondary total-pressure tube. For the ball-nose configuration, changes of the meridian angle of the total-pressure rake caused small errors at low angles of attack and large errors at angles from -10° to -20° and from 10° to 20° (fig. 5). The asymmetry exhibited by the static-pressure data with angle of attack was apparently caused by the interference or shielding effect induced by the rake of total-pressure tubes.

The addition of the transition strip to the configuration employing the nose boom (fig. 6) had negligible effect on the total pressures sensed by rake tubes ($\phi = 0^{\circ}$) at negative angles of attack and only small effect on total pressures sensed at positive angles of attack. Such small effects were generally within the estimated accuracy of measurement.

A comparison of total-pressure errors measured in flight at the NASA Flight Research Center and in the wind tunnel at $M = 0.6$, $y/d = 0.10$, and $\phi = 0^{\circ}$ (fig. 7) indicates reasonably close agreement for the ball-nose configuration throughout the angle-of-attack range for which flight data were available and for the configuration with the nose boom at angles of attack up to approximately 6°. The quantitative differences between flight and wind-tunnel data were generally within estimated measured accuracies except for the configuration with the nose boom at angles of attack greater than about 6°. In this case, the data discrepancies may have been associated with significant differences between the geometry of the nose boom (and attached instrumentation) used for flight tests and the simplified geometry of the nose boom used for wind-tunnel tests.

CONCLUDING REMARKS

Total-pressure errors indicated by a secondary pressure-tube installation on the upper surface of the fuselage of an X-15 research airplane with a nose boom were investigated by subsonic tests of models in a wind tunnel. The results indicated that the errors were apparently associated with the vorticity shed from the nose boom at positive angles of attack, since no serious errors were noted for pointed-nose and ball-nose configurations without nose booms. The results also indicated that the lower surface of the fuselage was a suitable circumferential location for a secondary total-pressure tube on a configuration with a nose boom. The total-pressure errors at the secondary-tube location were not significantly altered by changing the Mach number from 0.60 to 0.80 or by adding a transition strip to the configuration with a nose boom. The wind-tunnel test measurements were in reasonable agreement with flight measurements of total pressures sensed by secondary tubes on airplane configurations without and with nose booms.

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., February 8, 1962.

REFERENCES

1. Gracey, William: Wind-Tunnel Investigation of a Number of Total-Pressure Tubes at High Angles of attack - Subsonic, Transonic, and Supersonic Speeds. NACA Rep. 1303, 1957. (Supersedes NACA TN 3641.)

2. Letko, William: A Low-Speed Experimental Study of the Directional Characteristics of a Sharp-Nosed Fuselage Through a Large Angle-of-Attack Range at Zero Angle of Sideslip. NACA TN 2911, 1953.

TABLE I

ORDINATES FOR POINTED-NOSE CONFIGURATION

Station, in.	Radius, in.
0	0
1.8	.500
3.6	.936
5.4	1.320
7.2	1.640
9.0	1.915
10.8	2.138
12.6	2.310
14.4	2.425
16.2	2.480
17.5	2.500

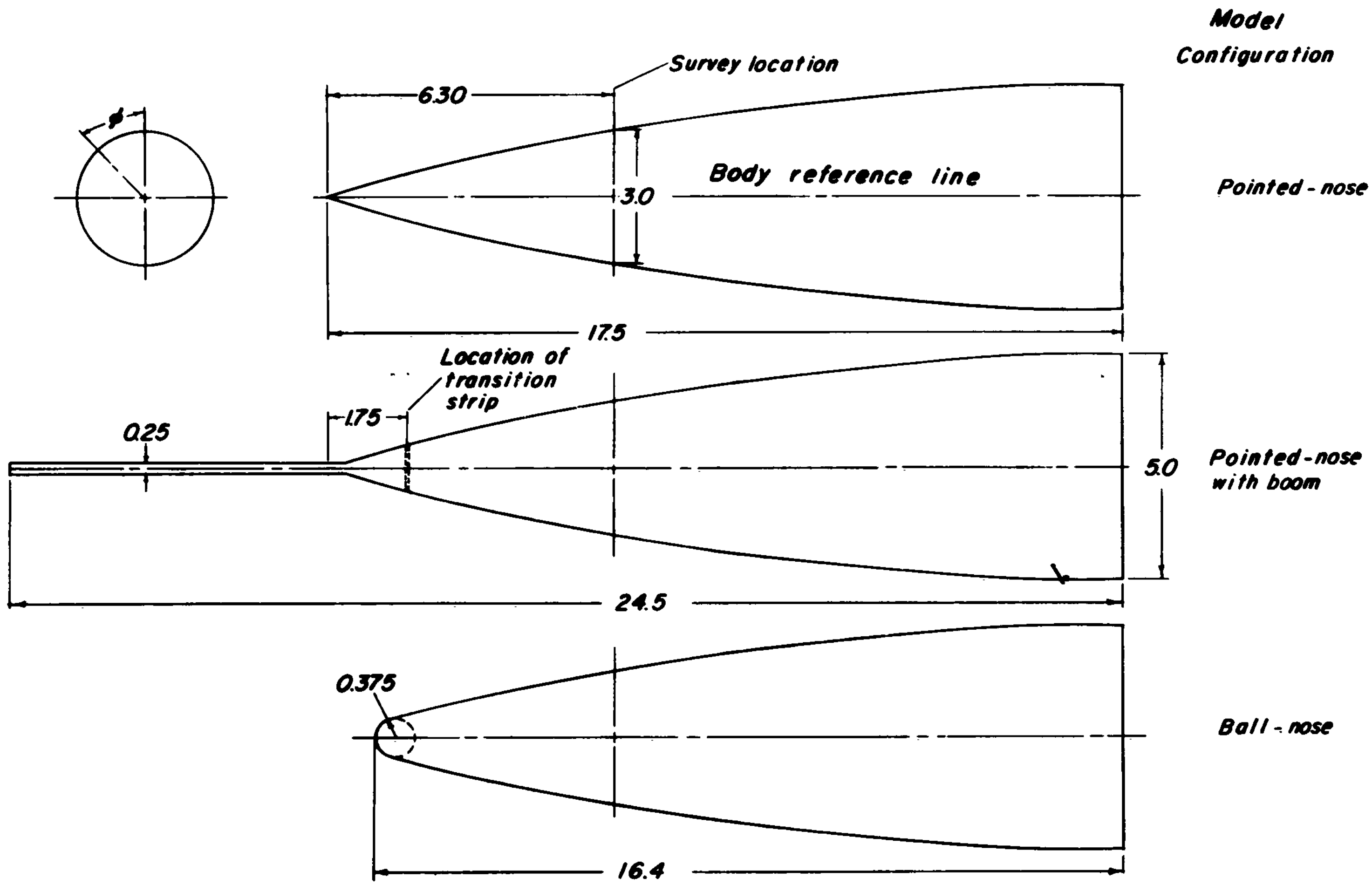
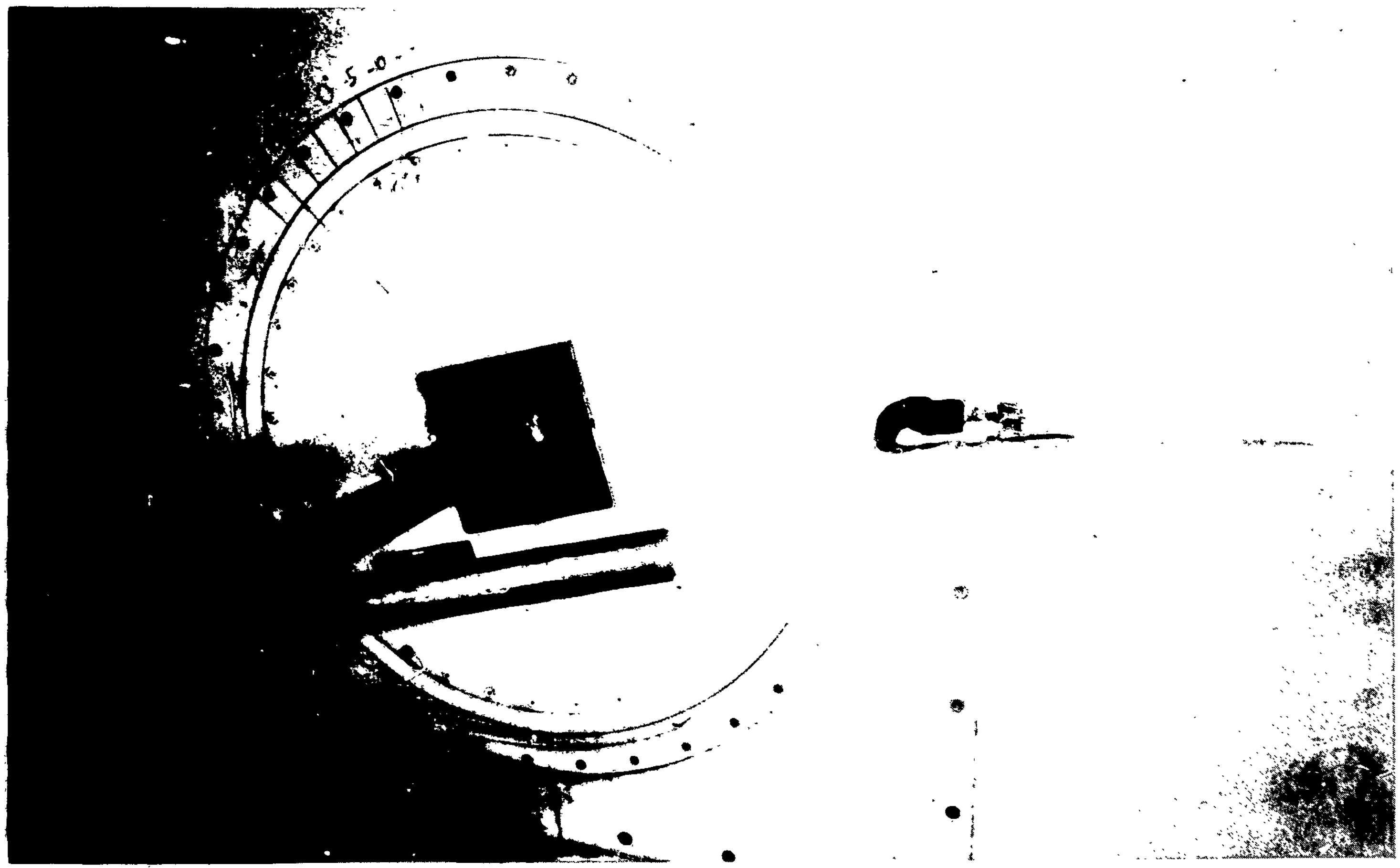


Figure 1.- Model configurations used for wind-tunnel tests. All dimensions in inches.



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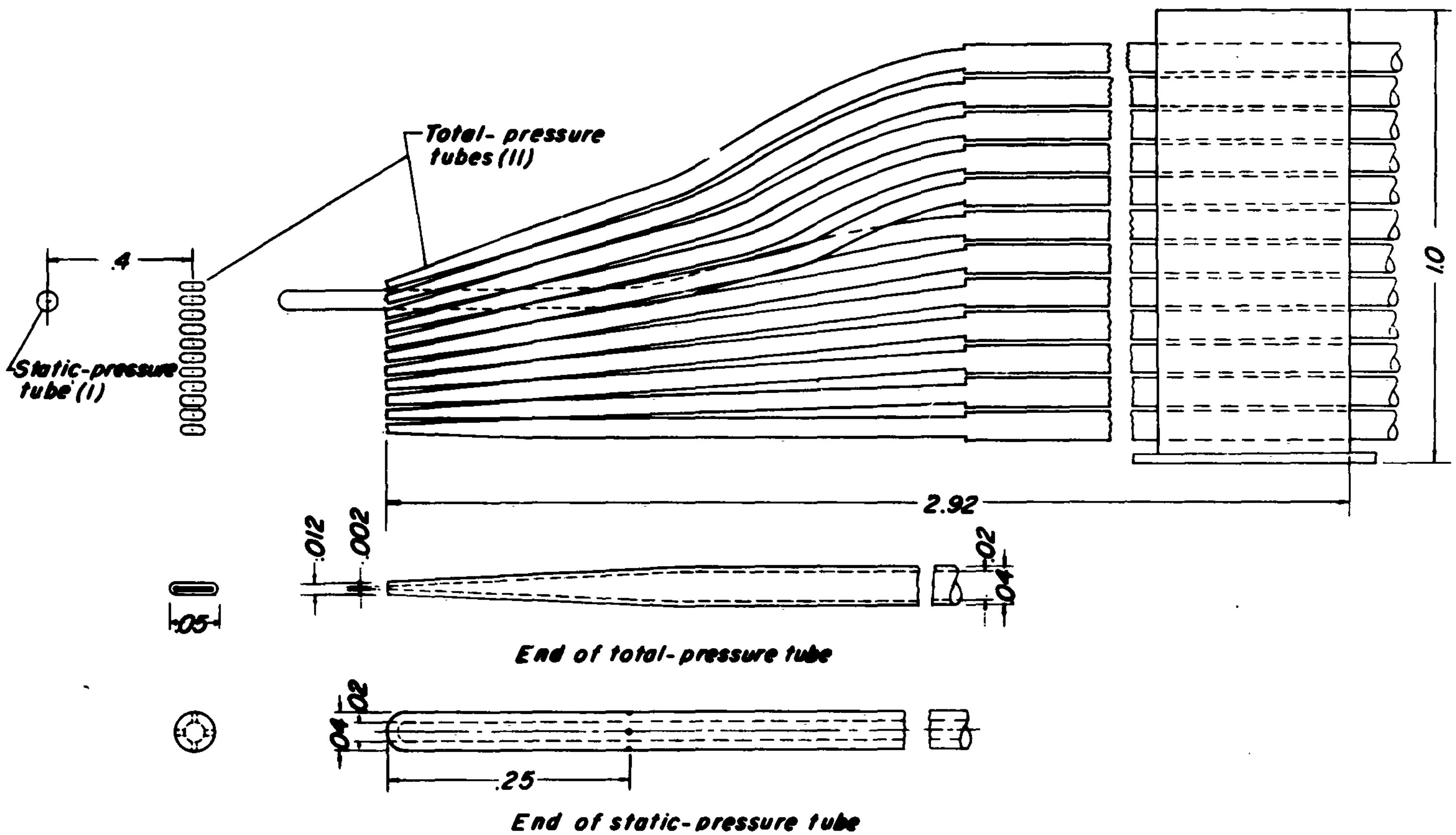
(a) Pointed-nose model with total-pressure rake on upper surface. $\phi = 0^{\circ}$.

Figure 2.- Test setup.



(b) Details of rake and pressure-sensing tubes employed for surveys near model surface. All dimensions in inches.

Figure 2.- Concluded.

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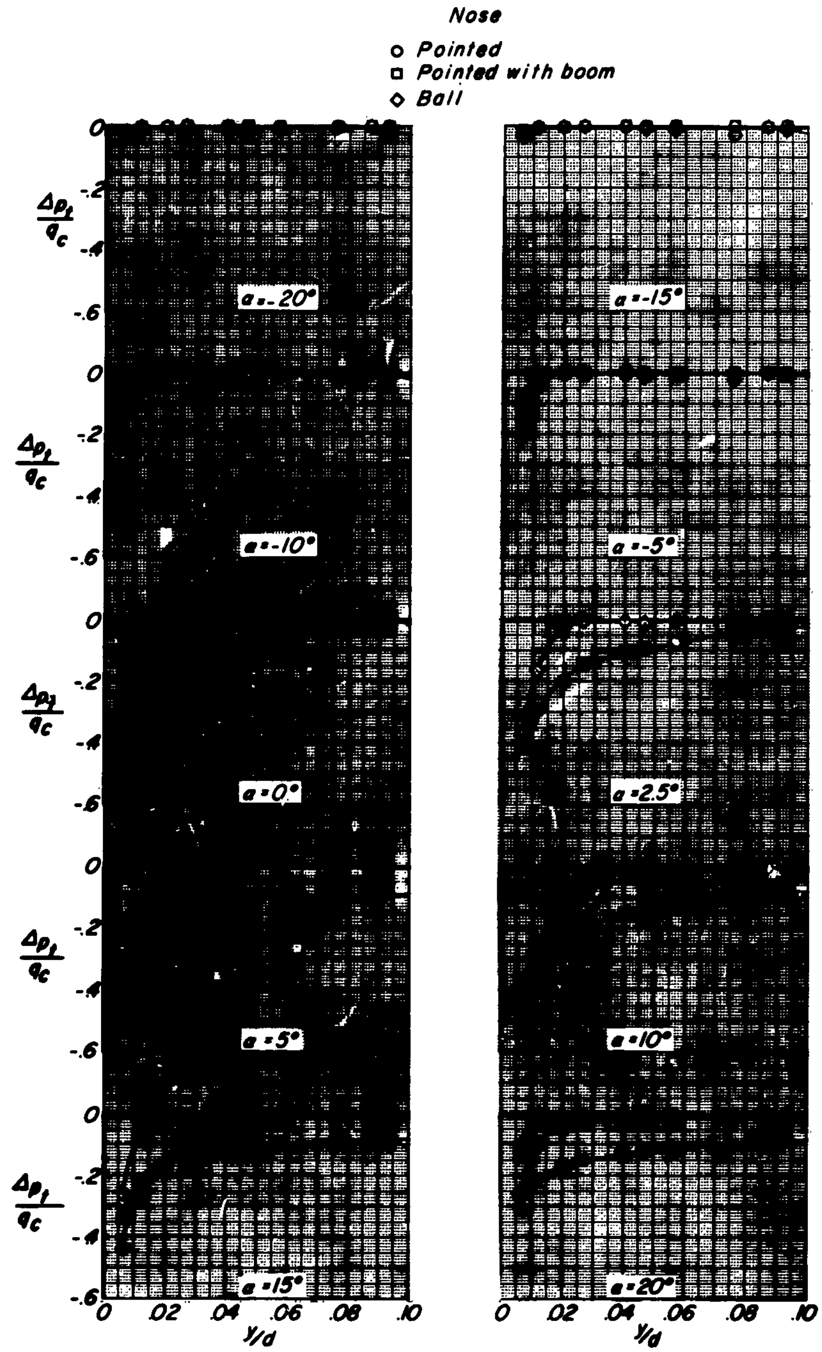
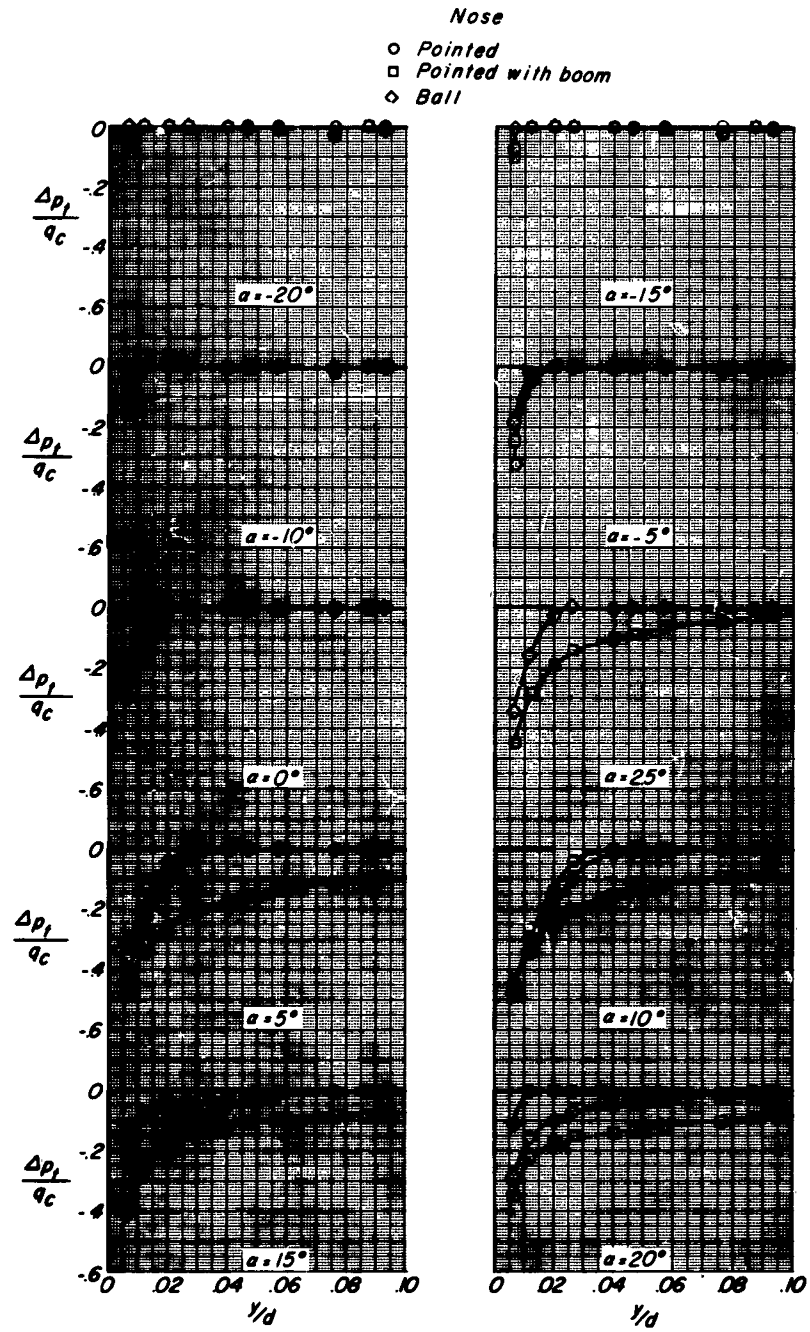


(a) Total-pressure error at M = 0.60.

Figure 3.- Effect of nose configuration. $\phi = 0^\circ$.



(b) Total-pressure error at M = 0.80.

Figure 3.- Continued.

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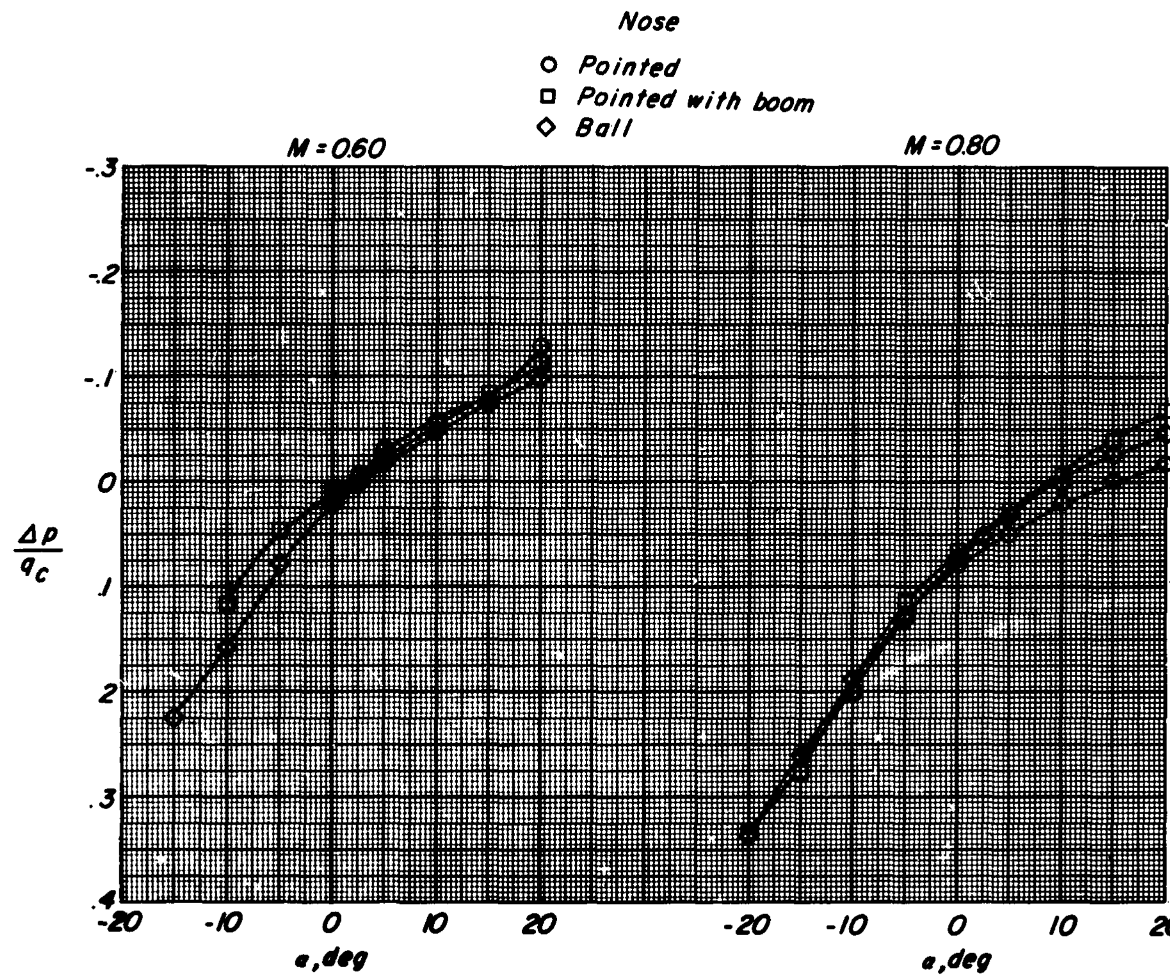
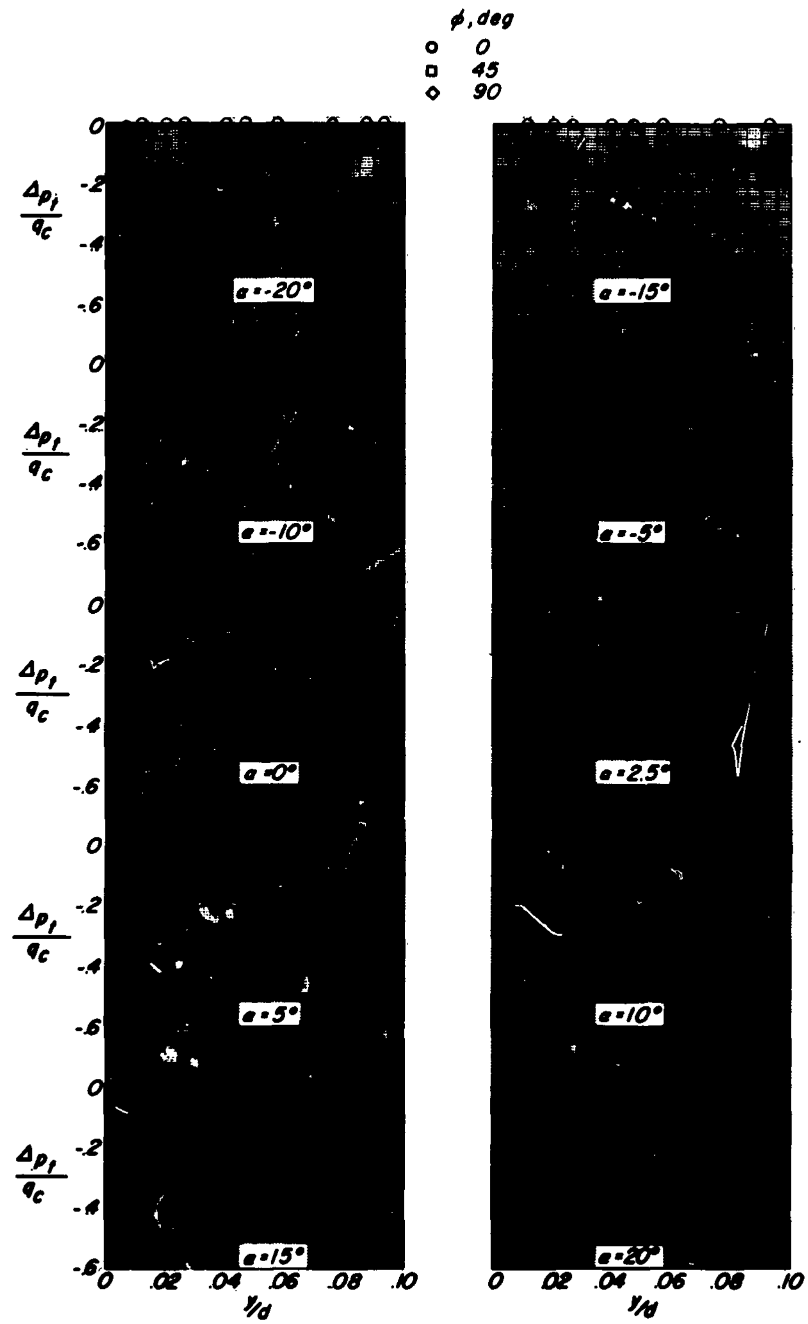


(c) Static-pressure error at $\frac{y}{d} = 0.10$.

Figure 3.- Concluded.



(a) Total-pressure error at M = 0.60.

Figure 4.- Surveys at various meridian angles for configuration with nose boom.

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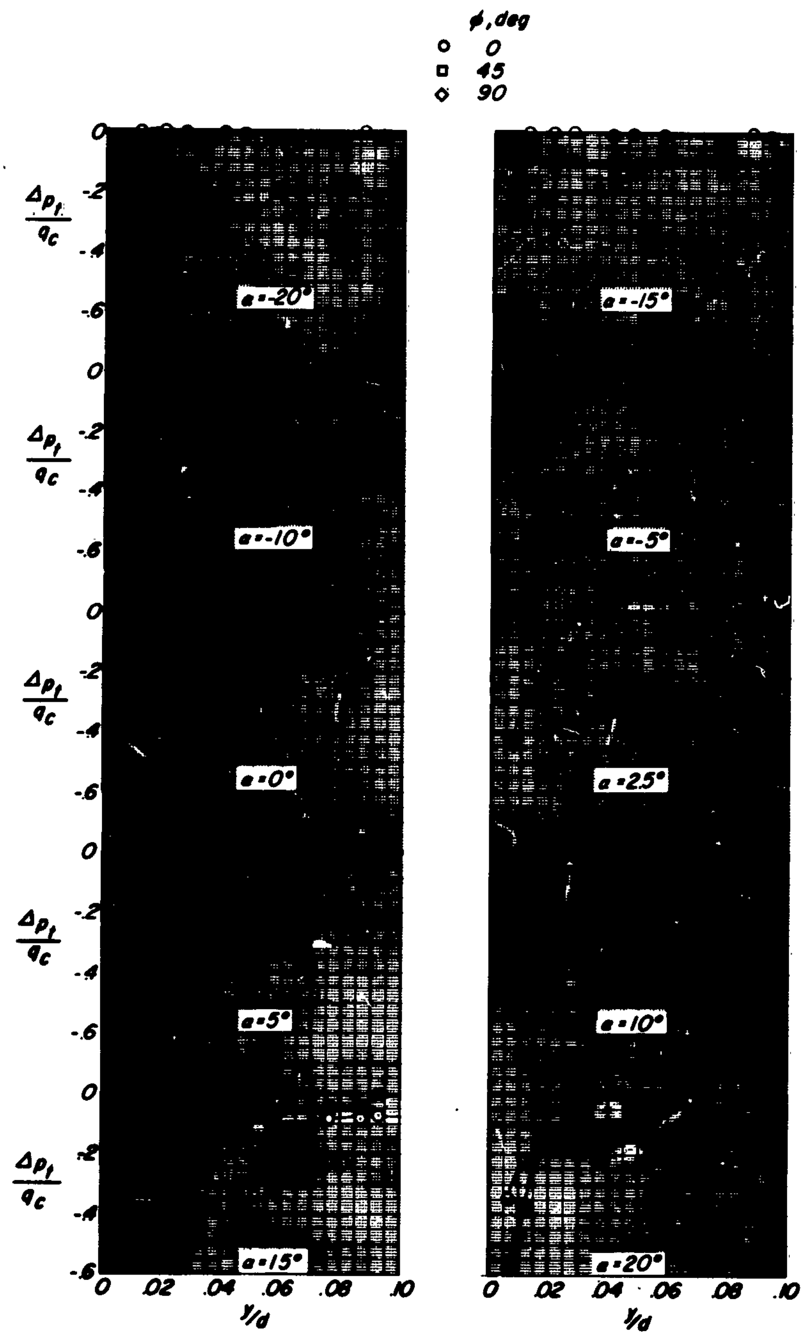

(b) Total-pressure error at M = 0.80.

Figure 4.- Continued.

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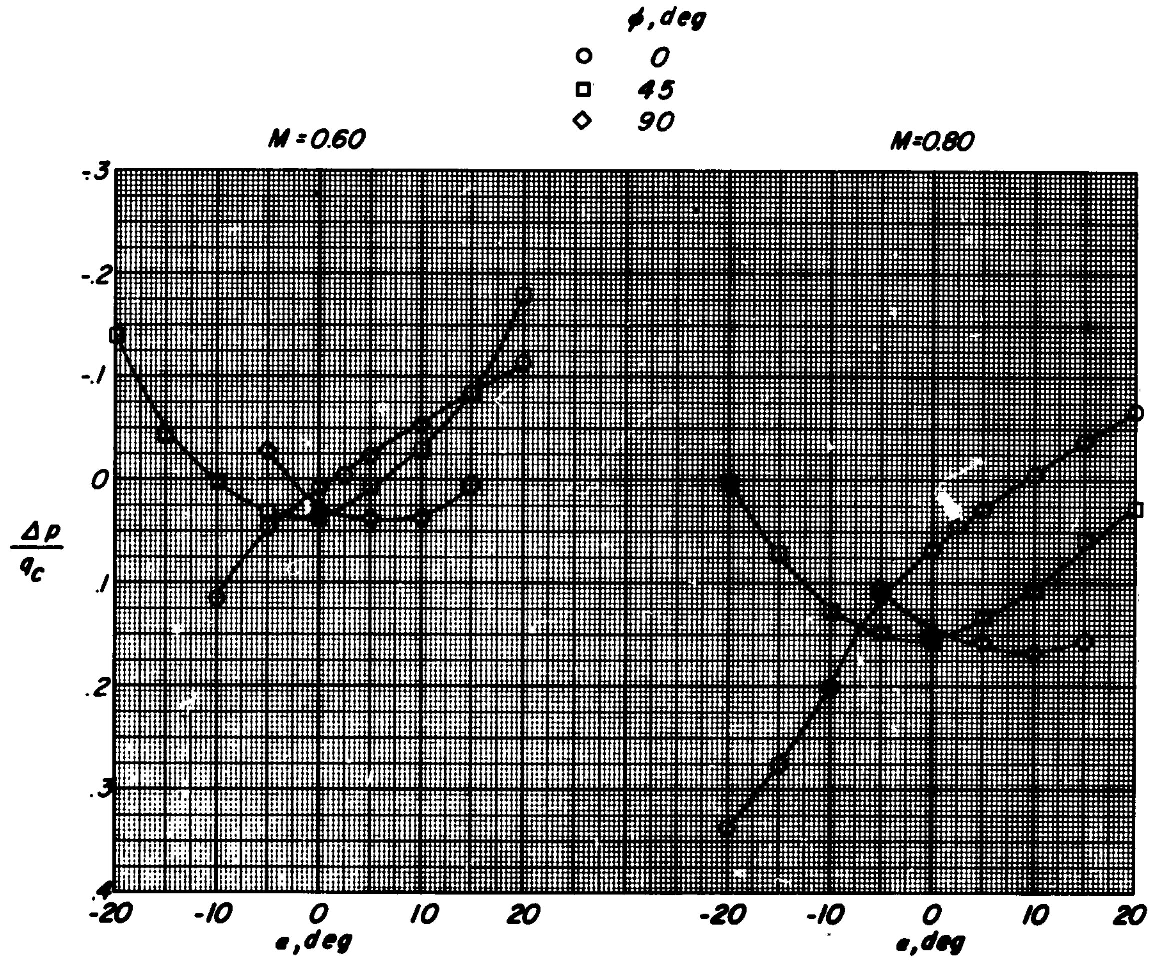

(c) Static-pressure error at $\frac{y}{d} = 0.10$.

Figure 4.- Concluded.

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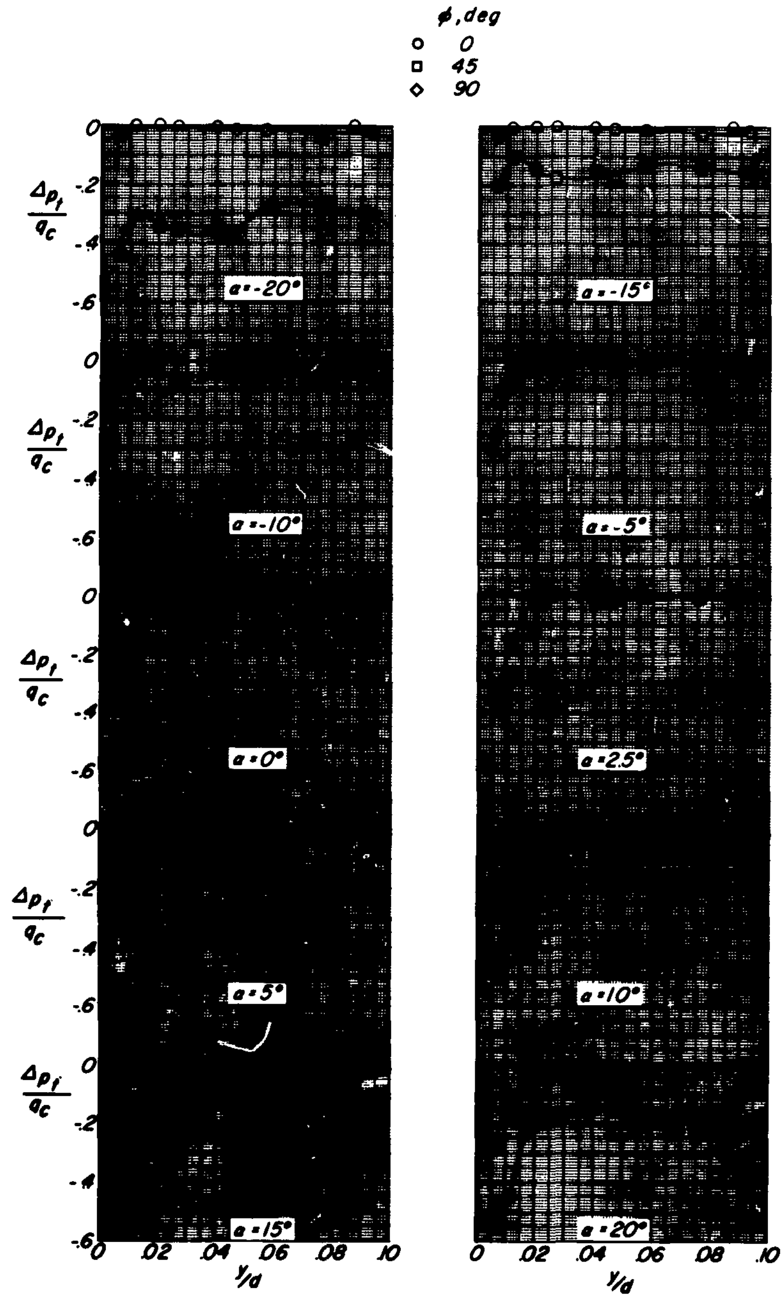
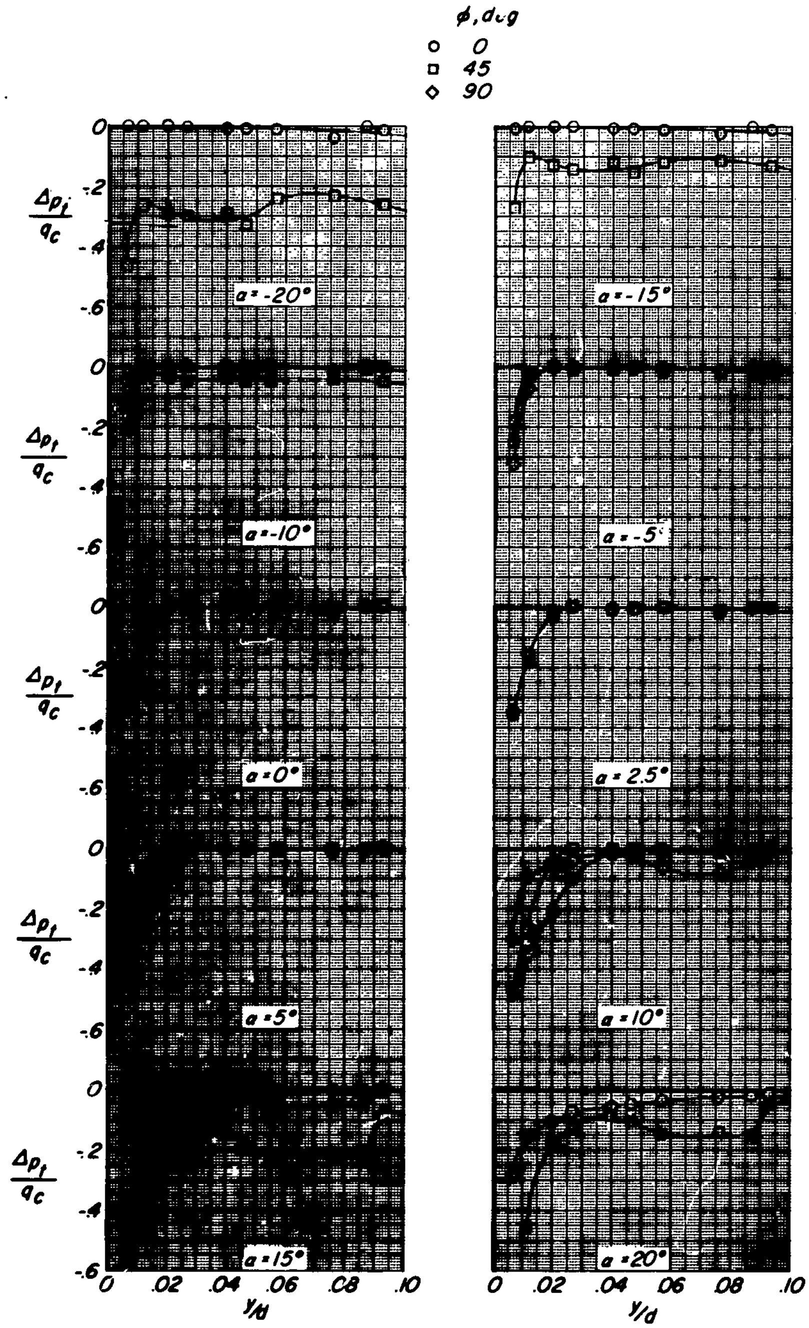


(a) Total-pressure error at M = 0.60.

Figure 5.- Surveys at various meridian angles for configuration with ball nose.



(b) Total-pressure error at M = 0.80.

Figure 5.- Continued.

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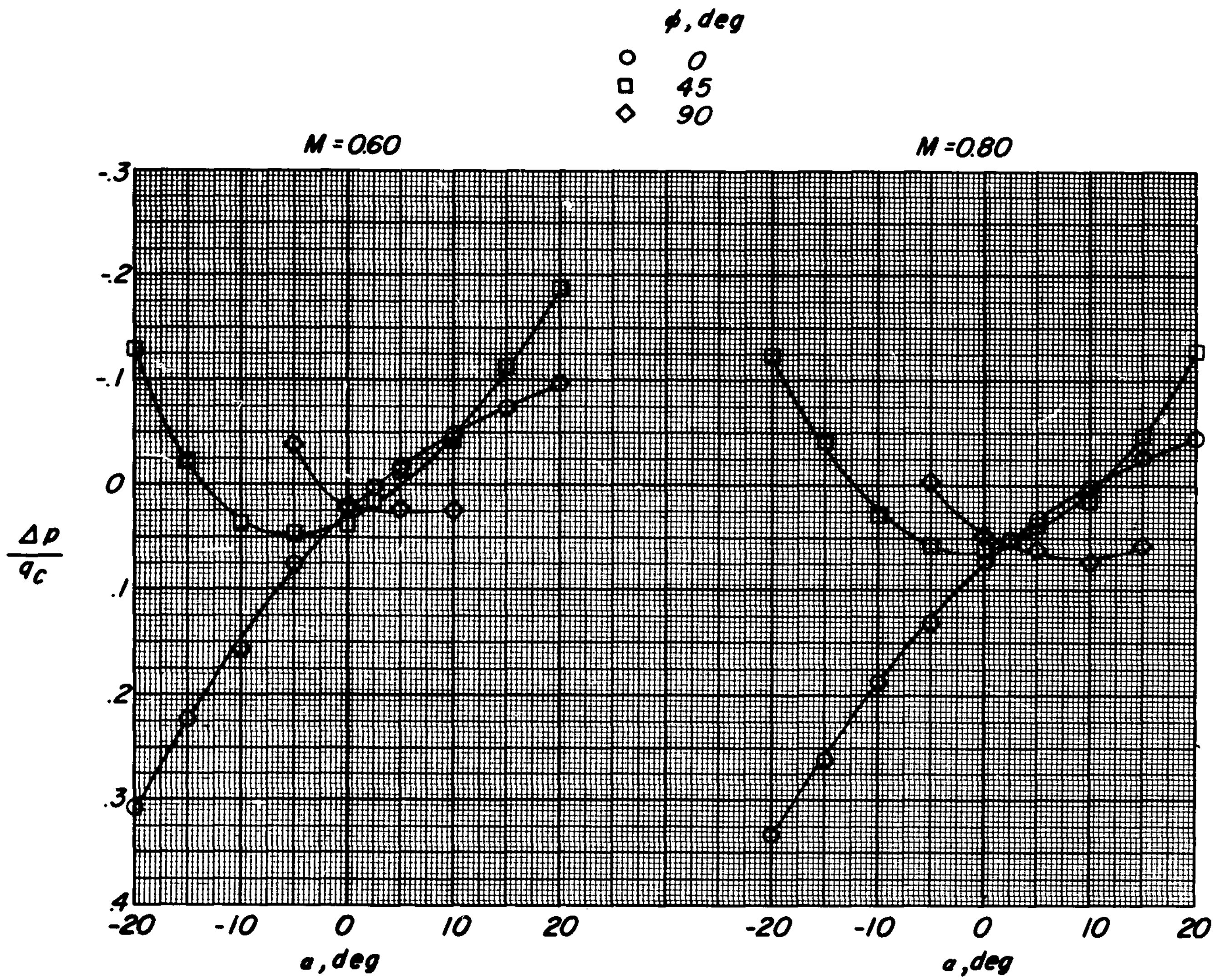
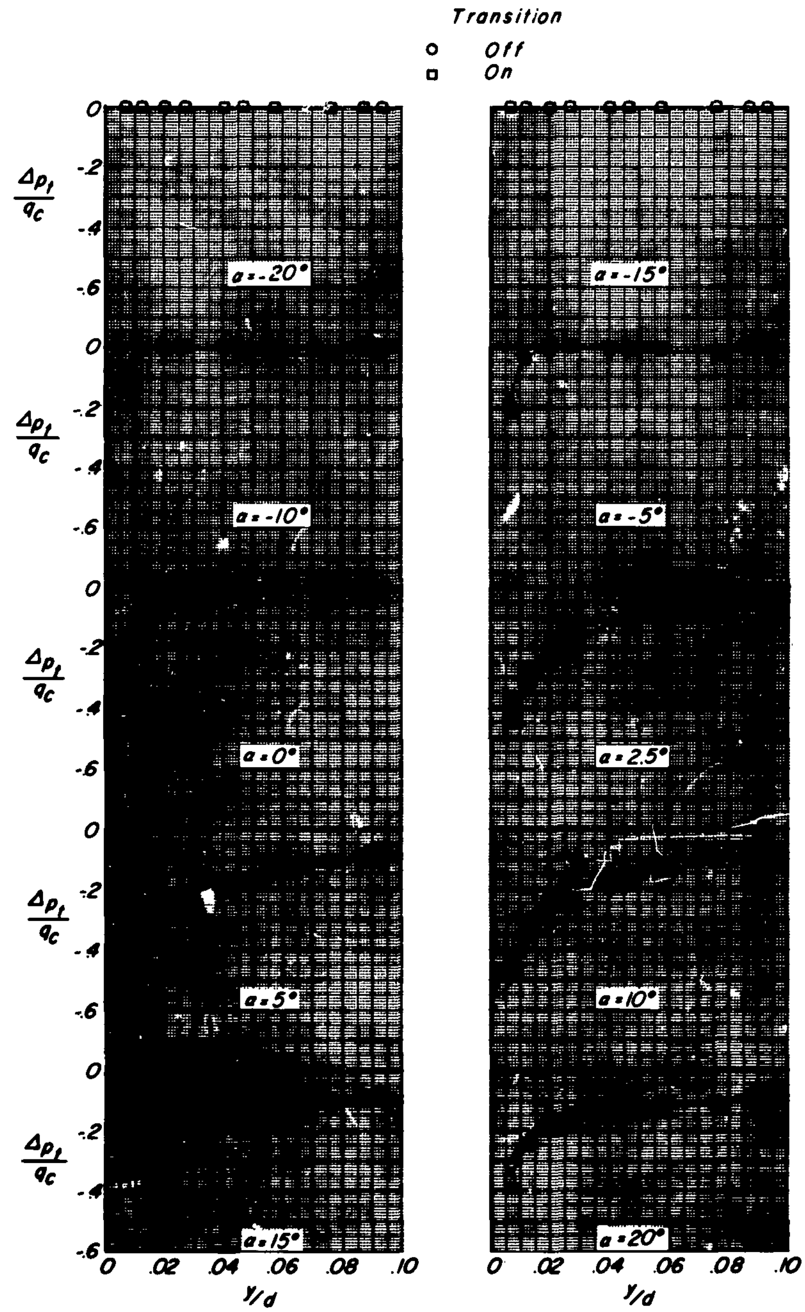


(c) Static-pressure error at $\frac{y}{d} = 0.10$.

Figure 5.- Concluded.



(a) Total-pressure error at M = 0.60.

Figure 6.- Effect of transition strip on configuration with nose boom. $\phi = 0^{\circ}$.

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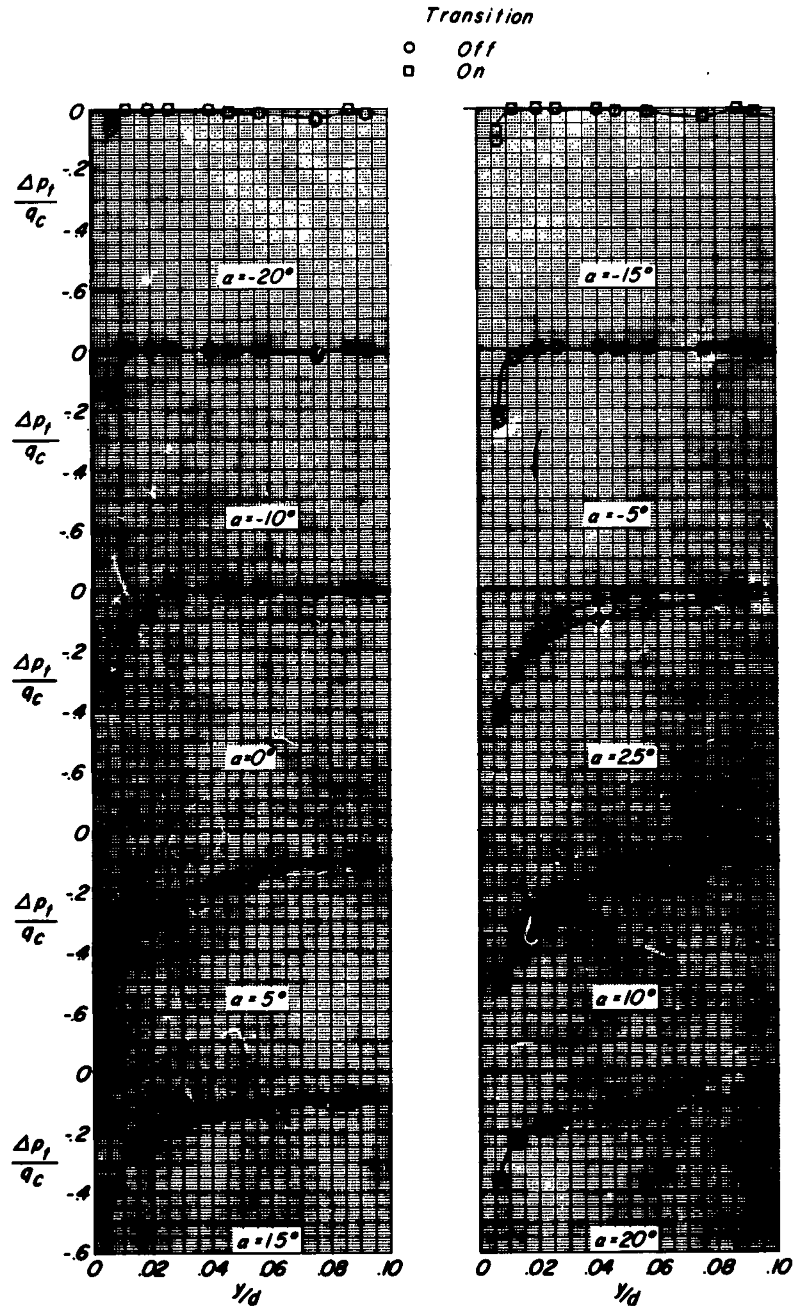
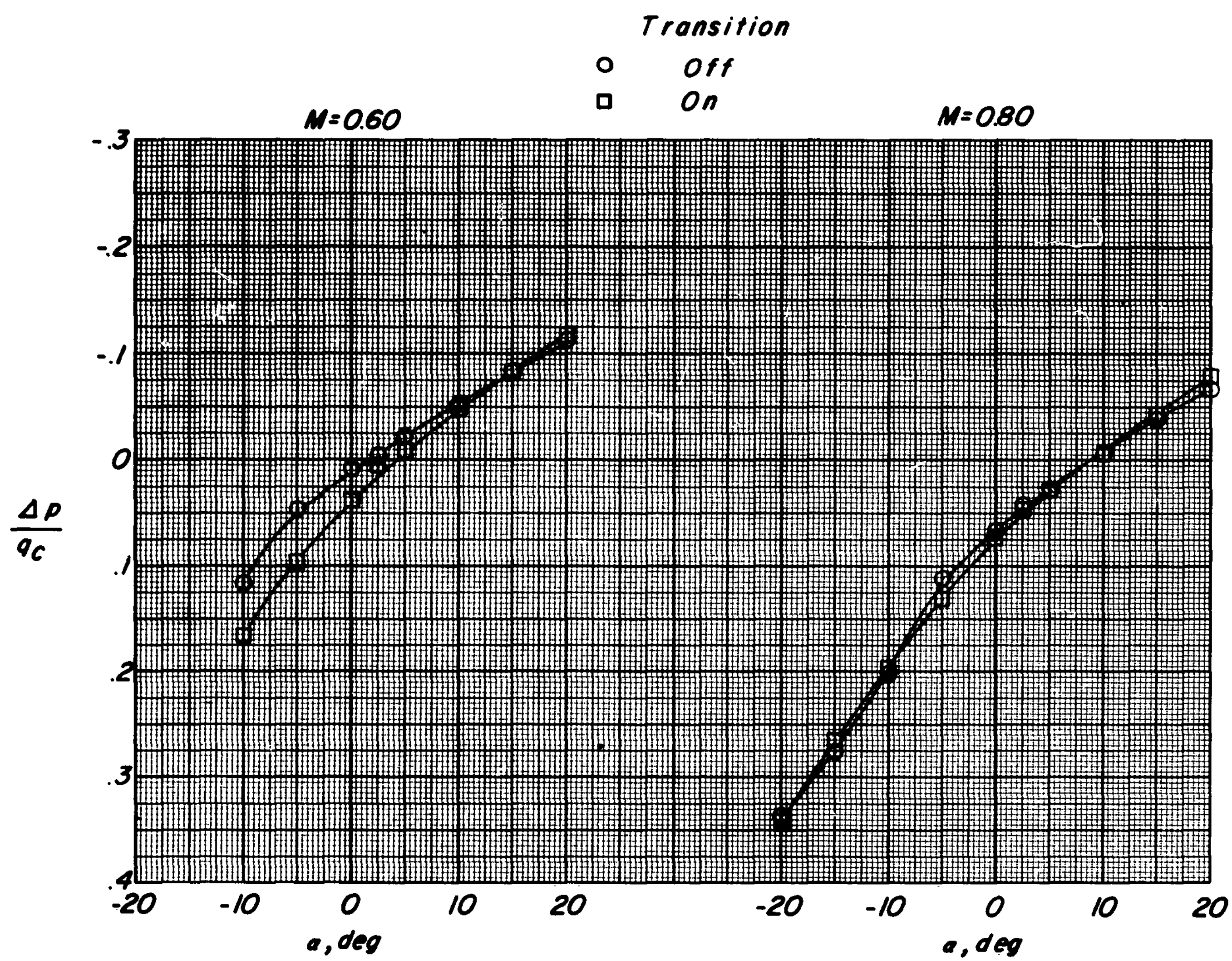


(b) Total-pressure error at M = 0.80.

Figure 6.- Continued.



(c) Static-pressure error at $\frac{y}{d} = 0.10$.

Figure 6.- Concluded.

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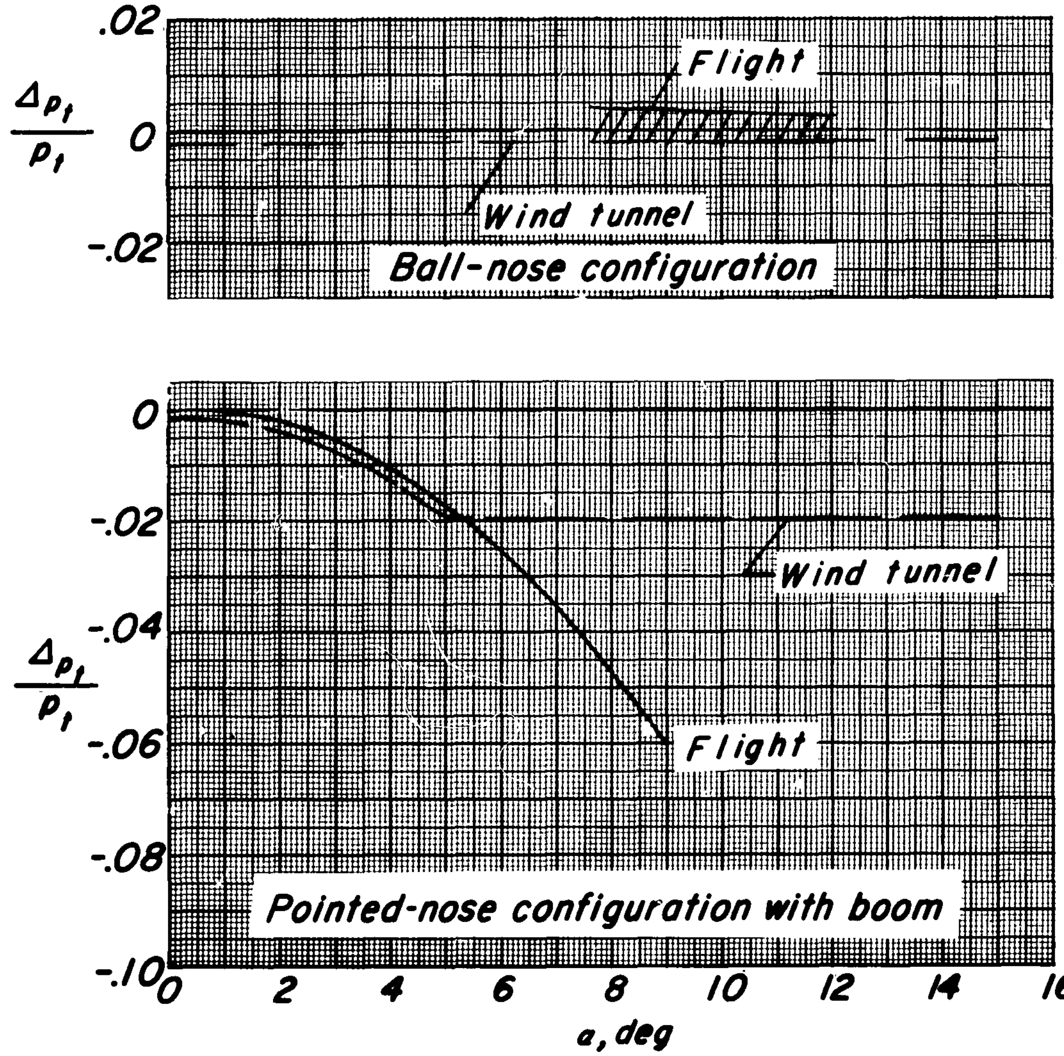

Figure 7.- Comparison of total-pressure errors as measured at the secondary-tube location in flight and in the wind tunnel. $M = 0.60$; $y/d = 0.10$; $\phi = 0^{\circ}$.

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A wind-tunnel investigation was conducted to determine the source of error indicated by a secondary total-pressure tube located on the upper surface of the fuselage of an X-15 research airplane with a nose boom. The test results indicated that the error of the secondary total-pressure tube was associated with vorticity shed by the nose boom and, also, that the error could be avoided by locating the tube on the lower surface of the fuselage. No serious errors were observed for the cases of ball-nose and pointed-nose model configurations without nose booms.

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